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HALF-COLLISIONS INDUCED BY SHORT UV LASER PULSES

AFOSR-89-0451

FINAL PROGRESS REPORT

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OVERVIEW

This program was centered on the study of half-collisions (in particular, dissociative ionization) of light diatoms (H_2, CO, O_2 and N_2) induced by intense (10^{13} - 10^{15} W/cm^2) 193 nm radiation . AFOSRfunding for this program started July 1, 1989 and ended June 30, 1993.
The program involved the development of a novel high peak power, shortduration UV laser system, the construction and testing of an ultra-high vacuum experimental chamber, the construction and testing of a time of flight detector for positive and negative charged particles and the implementation of computerized data acquisition and processing. This report details chronologically the various projects and accomplishments during the support period.

FIRST YEAR

I. Laser System

Two used commercial excimer lasers were available for this project: Lambda Physik Model 150ET and Model EMG200. Complete maintenance and upgrade was performed on both lasers. The first was set up as a XeCl oscillator used for pumping dye lasers, and the second was used as an amplifier for the short 193 nm pulses.

Several dye laser techniques for generation of pulses on picosecond time scale were tested and compared. Reliable approaches were identified and reproducible pulses on the order of 10 ps were obtained in the necessary spectral regions.

II. Experimental Chamber

Half-collisions experiments performed under intense laser conditions require extremely good vacuum conditions so that the background gas does not interfere with the gas under study. The primary hardware for the experimental chamber and time-of-flight measurement (with all metal seals and turbo-molecular pump) was procured or constructed and assembled. Different charged particle extraction and focusing schemes, such as parabolic mirror were

considered and tested. The scheme employed consisted flat extraction and acceleration regions and two arms; one for positive and one for negative ions or electrons.

III. Experiments

The prototype experiments started using our old chamber which is described in Review of Scientific Instruments article listed below. This chamber employed a simple extraction/acceleration grid structure and is capable of monitoring fluorescence and positive charged particles only. In the first series of experiments line narrowed 193 nm excimer laser was used to look for "Above Threshold Dissociation" in H_2^+.

IV. Personnel

The following personel was involved in the work sponsored by the contract:
Principal Investigators

J. Goldhar	1 Month
W.T. Hill, III	1 Month

Research Associates

J. Curry (Grad. Student)	1 Month
D. L. Hatten (Grad. Student)	12 Months
J. Zhu (Grad. Student)	2 Months

V. Publications and Presentations

1. "Spectroscopic Engineering of Multiphoton Fragmentation Channels in Diatomic Molecules", W.T. Hill III, B.P. Turner, S. Yang, J. Zhu, and D. L. Hatten, International Conference on Multiphoton Processes (ICOMP V), Paris, France, September 24-28, 1990

2. "Competition Between Multiphoton Ionization and Multiphoton Dissociation in Diatomic Molecules" , W. T. Hill III, Invited Presentation, XVII International Quantum Electronics Conference, Anaheim, CA, May 21-25, 1990

SECOND YEAR

I. Laser system

The final version of the picosecond laser system for half-collisions studies at 193 nm was constructed. Nearly transform limited and diffraction limited 10 picosecond were generated in the dye lasers that utilized two synchronized distributed feedback lasers operating at 705 and 532 nm. The output of the latter was amplified and frequency doubled in KDP crystal to generate 266 nm

radiation, which was mixed with 705 nm in BBO crystal to produce 193 nm seed pulse. The seed pulses were amplified up to 10 mJ in the 150ET Lambda physik excimer laser.

II. Experiments

First experiments with short pulses at 193 nm were conducted in the old chamber. The ion spectra obtained in CO and O_2 with the intense short pulses were significantly different from those obtained with long (10 ns) ArF^* pulses. For example, only C^+ ions were observed with long pulses while O^+, O^{++}, CO^+, C^+ and C^{++} are observed with short intense pulses. These observations were the first of their kind at this wavelength and intensity.

III. Data Acquisition and Processing System

An AT computer was set up for data acquisition and instrument control (CAMAC modules and HP digital oscilloscope) and a RISC based work station (DECstation 5000) for data analysis and model computation. These computers are networked via ETHERNET so that online display of acquired data can be accomplished. Software for the system was developed.

IV. Personnel

The following personel was involved in the work sponsored by the contract:
Principal Investigators

J. Goldhar	1 Month
W.T. Hill, III	1 Month

Research Associates

Y. Cui (Grad. Student)	10 Months
D. L. Hatten (Grad. Student)	12 Months
J. Zhu (Grad. Student)	12 Months
S. Yang (Grad. Student)	7 Months
S. Wilson (Undergrad. Student)	140 Hours

V. Publications and Presentations

1. "Generation of Picosecond Pulses Using a Simple Distributed Feedback Dye Laser with Holographic Transmission Grating," T. N. Ding, Y. Cui, J. Goldhar, D. L. Hatten, W. T. Hill III, and T. Mikes - CLEO, paper # CTuW50, 1991

2. "Intermediate States in Multiphoton Fragmentation of Small Molecules", W.T. Hill III, S.Yang, J. Zhu, D. L. Hatten, Y. Cui, and J. Goldhar, NATO Advanced Research Workshop on Coherence Phenomena in Atoms and Molecules in Laser Fields, May 5 -10, 1991, McMaster University, Hamilton, Ontario, Canada.

3. "Photofragmentation II: Laser Induced Molecular Dynamics", International Workshop on the Physics and Modern Applications of Lasers", W. T. Hill III, Invited Presentation, Universite Ceikh Anta Diop de Dakar, Dakar, Senegal, May 22-28, 1991

THIRD YEAR and FOURTH YEARS

I. Experiments and Analysis

The entire experimental system was operational and massive amount of new data on ion time-of-flight spectra of N_2, O_2 and CO induced by intense field ($10^{15}W/cm^2$) dissociative ionization at 193 nm was collected. Energy and charged state information was extracted from the data. Theoretical analysis and channel identification was made for some species and is in progress for the others. Our most important contribution to the field is a clarification of the phenomenon known as a "Coulomb Explosion", the electrostatic dissociation of a multiply charged multiatom system. In a Physical Review Letter we explained how true Coulomb explosions can only be observed under special conditions and in most cases, intense-field induced dissociation should be renamed "Quasi-Coulomb Explosions". The reason is simply that the principal potential curves responsible for dissociation are not represented well by Coulomb curves since the remaining electrons can provide binding interaction at small interatomic distances.

II. Personnel

The following personel was involved in the work sponsored by the contract:
Principal Investigators

J. Goldhar	1 Month
W.T. Hill, III	1 Month

Research Associates

Y. Cui (Grad. Student)	18 Months
L. Hatten (Grad. Student)	20 Months
J. Zhu (Grad. Student)	1 Months
S. Yang (Grad. Student)	1 Months

III. Publications and Presentations

1. "Role of Non-Coulombic Potential Curves in Intense-Field Dissociative Ionization of Diatomic Molecules", W.T. Hill,III, J. Zhu, D.L. Hatton, Y. Cui, J. Goldhar, and S. Yang, Phys. Rev. Letters, Vol. 69, p. 2646 (1992)

2. "Generation of Intense 10 ps, 193 nm Pulses Using Simple Distributed Feedback Dye Lasers and ArF* Amplifier", D.L. Hatten, Y. Cui, W.T. Hill, T. Mikes and J. Goldhar, Applied Optics, Vol. 31, p.7042, (1992).

3. "Frequency Tuning of a Distributed Feedback Dye Laser with Two Transmission Gratings", Y. Cui, T.N. Ding, D.L.Hatten, W.T.Hill, J.Goldhar, Applied Optics (In Press).

4. "Intermediate States in Multiphoton Fragmentation of Small Molecules", W. T. Hill, III, S. Yang, D.L. Hatten, Y. Cui, J. Goldhar, and J. Zhu, NATO ASI Series Coherence Phenomena in Atoms and Molecules in Laser Fields, ed. A.D. Bandrauk and S.C. Wallace p. 153 -161 (Plenum Press, New York, 1992)

5. "Intense Field Multiphoton Fragmentation of Diatoms with 193 nm Radiation", J. Zhu, D.L. Hatten, Y. Cui, S. Yang, J. Goldhar, W.T. Hill III, 1992 Meeting of APS Division of Atomic Molecular and Optical
Physics, Chicago IL, May 19-22, 1992.

6. "Multiphoton Dissociation Ionization Dynamics of Light Diatomic Systems Induced by 10 ps, 193nm Radiation", W. T. Hill III, J. Zhu, Y. Cui, J. Goldhar and S. Yang, Multiphoton Processes Gordon Conference, Colby-Soyer College, New London, New Hampshire, June 8-12, 1992.

7. "Quasi Coulomb Explosion Model of Multiply Ionized Diatoms", W.T. Hill III, D.L. Hatten, J.Zhu, Y. Cui, and J. Goldhar, Proceedings of ICOMP VI (in Press)

8. "Frequency tuning of a distributed feedback dye laser with two transmission gratings", Y. Cui, T.N. Ding, J. Goldhar and W.T. Hill III, CLEO-93 paper #CWD4 Baltimore, Md. May 2-7, 1993

9. "Quasi Coulomb-explosion model of intense field dissociative ionization of Diatoms", J. Zhu, D.L. Hatten, W. T. Hill III, Y. Cui and J. Goldhar, QELS-93, Baltimore, Md. May 2-&, 1993

10. "DISSOCIATIVE IONIZATION OF N_2 IN THE INTENSE UV LASER FIELD AT 193 nm", J. Zhu, D.L. Hatten, W. T. Hill III, Y. Cui and J. Goldhar, To be submitted to Phys Rev A.

11."Application of a Quasi-Coulomb Explosion Model to the Dissociative Ionization of CO and O_2", D.L. Hatten, J. Zhu, W. T. Hill III, Y. Cui and J. Goldhar to be submitted to Phys. Rev. A.